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Electronic Circuit Responsiveness Determination

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Abstract: The article is devoted to the determination of electronic circuit sensitivity problem that arises in the analysis and design of electronic devices. Two kinds of RC - circuit are considered: linear and nonlinear. Mathematical problems, based on mathematical models formulated, in which the parameters expected to change elements of the considered circuits, were stated. The solution of mathematical problems for different values ??of these parameters allowed analysis of the impact of these changes on the change of voltages and currents in the circuits to be conducted. For a linear circuit, an analytical solution for the nonlinear case has been obtained and for the nonlinear one the numerical method for solving problems has been applied. An approach to the determination of sensitivity proposed in this article can be extended to any type of circuit.

Key words: Circuit · Sensitivity · RC - circuit · Linear circuit · Circuit sensitivity · Nonlinear circuit

INTRODUCTION

Obviously, the characteristics of the electronic circuit depend on the parameters of its elements. In addition it is known that the electronic circuits are affected not only by external actuation (current, voltage, etc.), but also values of the component parameters can change under the influence of various factors [1]. Factors affecting the change in the parameters of the circuit elements can be: changes in atmospheric conditions, temperature mode, deterioration, aging, replacement of circuit elements and others [2, 3]. In the process of production and operation of electronic devices values of element parameters may also differ from the calculated values. Obviously, if at some point in time occurs a change of parameters in the circuit, then the process in the circuit will be different. These changes of the parameter values of the electronic circuit elements may be undesirable for the normal functioning of the device, as they are the cause of its malfunction. Because the quality of the electronic device operation mostly depends on the change in its characteristics [4].

On the other hand, the calculation of responsiveness plays an important role in the design of electronic devices, used for the analysis of different options of their schemes and choosing the best version of them, i.e. for circuit parameter optimization [1-3].

Due to this fact it becomes necessary to assess the impact of changes in the element parameters to the change in the characteristics of the electronic device. Such a task is relevant. To solve this problem, we introduce the concept of an electronic circuit responsiveness to the changes in its parameters [1, 2]. Here, the term “responsiveness” refers to the reaction of the circuit to the change of the parameter in its element. To quantify the responsiveness, the ratio of change in output parameter to the change in the element parameter is used, which is measured in percent [4].

Researches by many authors are dedicated to the study of the problem of calculating the quantitative assessment of responsiveness [1-8]. Concept of responsiveness was introduced in the works of G. Bode (Bode H.W. 1945). Solution to the problem related to the determination of responsiveness, has some difficulties of computational nature. Because the mathematical modeling of the processes in electronic circuits leads to a system of differential equations whose integration will require the use of numerical methods and computer facility. The

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solution of a mathematical problem for the general case does not make sense, since because of the diversity of practical problems it is difficult to bring them to the same type and suggest a unified way to solve them. Therefore, it is advisable to formulate and solve the problem of determining the responsiveness of a particular electronic circuit.

This article discusses the solution to the responsiveness determination problem via an example of an RC-circuit. Here we consider two variants of the formulation of the electronic circuit responsiveness determination problem: linear and nonlinear. In the first case in which a linear electronic circuit is considered, an analytical solution of the problem was obtained and in the second case a numerical method was used; computational experiment was conducted. The results of these solutions were analyzed and certain conclusions were made.

State of the problem. It is known that for the analysis and design of electronic circuits a mathematical model of the possible processes that can occur in a particular scheme under consideration is being developed. As a result of modeling the differential and algebraic equations will be obtained. In most cases, a mathematical problem related to the Cauchy problem for the system of ordinary differential equations will arise. Differential equations are solved with respect to the first derivatives of the unknown functions. The Cauchy problem for these differential equations in the general formulation can be formulated as follows: it is required to solve a system of equations:

$$\frac{dx_i}{dt} = f_i(x_1, x_2, \ldots, x_n, [alpha]_1, [alpha]_2, \ldots, [alpha]_m) \tag{1}$$

with the initial conditions being

$$x_i(0) = a_i, \quad i = 1, 2, \ldots \cdots, n, \tag{2}$$

Here, $[alpha]_j$ parameters of the circuit under consideration, $j = 1,2,\ldots.,m$.

Solution of the Cauchy problem (1) - (2) allows to determine the unknown functions $x_i(t)$ depending on the parameters $[alpha]_j$ $j = 1,2,\ldots.,m$. As a quantitative evaluation of responsiveness it is common to use the partial derivatives of the functions $x_i(t)$ with respect to parameters $[alpha]_j$:

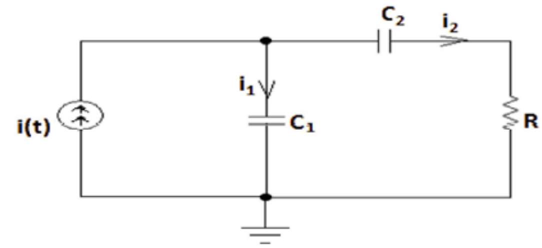


Fig. 1: Linear RC-circuit

$$u_{ij} = \frac{\partial x_i}{\partial [alpha]_j}, \quad i = 1, 2, \ldots, n, \quad j = 1, 2, \ldots, m. \tag{3}$$

Here, u_{ij} is called the function of responsiveness with respect to the corresponding parameter $[alpha]_j$.

Now it is necessary to consider specific examples of electronic circuits, for which the problem of determining the responsiveness of its parameters will be solved.

Problem statement for linear circuit. For a linear circuit the problem can be stated with any number of elements. This will lead to the increase in the number of equations and unknown quantities. However, the statement of the linear problem, the method of mathematical modeling of the process occurring in this circuit and also the solution method for a mathematical problem can be the same as for a simple circuit. Therefore, it is possible to restrict to consideration of a simpler scheme. Let's consider the following diagram of RC-circuit (Figure 1).

Using Kirchhoff's Laws for the given circuit, it is possible to obtain the following system of differential equations [9,10]:

$$\begin{cases} \dfrac{du_1}{dt} = \dfrac{u_2 - u_1}{RC_1} + \dfrac{i(t)}{C_1}, \\ \dfrac{du_2}{dt} = \dfrac{u_1 - u_2}{RC_2}, \end{cases} \tag{4}$$

where R - resistance of the resistor; C_1 and C_2 - capacitor capacitances; $u_1(t)$ and $u_2(t)$ - capacitor voltages; $i(t)$ - current at the source; t - time

Without the loss of generality, it is possible to assume that at the initial moment (at t = 0) the following initial conditions were given:

$$u_1(0) = 0, \quad u_2(0) = 0. \tag{5}$$

The rest of the unknown variable quantities (currents) may be determined with the help of the following formulas:

$$i_1(t)=C_1\frac{du_1}{dt}, \quad i_2(t)=C_2\frac{du_2}{dt}. \tag{6}$$

The system of equations is linear with respect to the unknown functions. Therefore the solution of the Cauchy problem (4) - (5) for this system can be determined analytically.

Before we begin to address this problem, it is advisable to shift to dimensionless variables. To do this, the so-called characteristic values are chosen. Let the characteristic values be: U_o- voltage, $\frac{U_0}{R}$ – current and T- time. The transition to dimensionless variables is done by using the following replacement of variables:

$$u_1 = x_1 \cdot U_0, \quad u_2 = x_2 \cdot U_0, \quad i = z\cdot\frac{U_0}{R}, \quad t = T\cdot t'. \tag{7}$$

Here, x_1, x_2, z, t' – dimensionless quantities. In further calculations the bar above *t* may be omitted and it may be considered a dimensionless quantity.

Replacement of the variables (7) allows us to obtain from the system of equations (4) the following system with respect to dimensionless values:

$$\begin{cases} \dfrac{dx_1}{dt} = \dfrac{1}{[alpha]_1}\cdot\left[x_2(t) - x_1(t) + z(t)\right], \\ \dfrac{dx_2}{dt} = \dfrac{1}{[alpha]_2}\cdot\left[x_1(t) - x_2(t)\right], \end{cases} \tag{8}$$

where $[alpha]_1 = \frac{RC_1}{T}$ and $[alpha]_2 = \frac{RC_2}{T}$ - dimensionless values

From the initial conditions (5) follows

$$x_1(0) = 0, \quad x_2(0) = 0. \tag{9}$$

Solution of the problem (8)-(9) allows to determine the unknown functions $x_1(t)$ and $x_2(t)$ whose analytical formulas include the parameters C_1 and C_2 It is required to assess the changes of the parameter values C_1 and C_2 to the change in the functions $x_1(t)$ and $x_2(t)$.

Solution of the linear problem. Analytical solution of the Cauchy problem (8) - (9) determines the dimensionless values of voltages, which may be represented in form of the following formulas:

$$\begin{cases} x_2(t) = \dfrac{1}{[alpha]_1\cdot[alpha]_2}\cdot\displaystyle\int_0^t (\exp)^{-[alpha]\cdot[xi]}\cdot G([xi])\cdot d[xi], \\ x_1(t) = x_2(t) + \dfrac{1}{[alpha]_1}\cdot(\exp)^{-[alpha]t}\cdot G(t), \end{cases} \tag{10}$$

where: $[alpha] = \dfrac{[alpha]_1 + [alpha]_2}{[alpha]_1\cdot[alpha]_2}$,

$$G(t) = \int_0^t (\exp)^{[alpha]\cdot[xi]}\cdot z([xi])\cdot d[xi]. \tag{11}$$

If we consider partial case, when $i(t) = \frac{U_0}{R}\cdot\sin(\omega\cdot t)$, i.e. $z(t) = \sin(\omega\cdot t)$, then the formulas (10) will be written in the following form:

$$\begin{cases} x_2(t) = \dfrac{[alpha]}{[alpha]_1[alpha]_2}\cdot\dfrac{1}{[alpha]^2+\omega^2} \\ \left[\dfrac{1}{\omega}(1-\cos\omega t) + \dfrac{\omega}{[alpha]^2}(1-\exp(-\alpha t))\right] - \dfrac{1}{[alpha]}\sin\omega t; \\ x_1(t) = x_2(t) + \dfrac{[alpha]}{[alpha]_1}\cdot\dfrac{1}{[alpha]^2+\omega^2} \\ \left[\sin\omega t + \dfrac{\omega}{[alpha]}\cdot\exp(-[alpha]t) - \dfrac{\omega}{[alpha]}\cos\omega t\right]. \end{cases} \tag{12}$$

Dimensionless values of the currents are determined with the help of the following formulas:

$$\begin{cases} y_2(t) = \dfrac{[alpha]}{[alpha]_1}\cdot\dfrac{1}{[alpha]^2+\omega^2}\cdot \\ \left[\sin\omega t + \dfrac{\omega}{[alpha]}(\exp(-[alpha]t) - \cos\omega t)\right]; \\ y_1(t) = z(t) - y_2(t); \end{cases} \tag{13}$$

For determining of the responsiveness of the given scheme to the change in the parameters C_1,C_2 -capacitor capacitances the calculation of values x_1,x_2,y_1,y_2 is performed for various values of these parameters. Due to transition to dimensionless values, in the given case instead of the values C_1,C_2 the parameters $[alhpa]_1$ and $[alhpa]_2$ are considered.

To perform these calculations some assumptions need to be made. Let the current of the source be alternating and its change be given in a form of a sinusoid: $z(t) = \sin(2[pi]f\,t)$, where the frequency f=50 Hz.

Table 1: Values of the parameters [alpha]$_1$ and [alpha]$_2$

Values	1	2	3	4	5
[alpha]$_1$	0,15	0,165	0,15	0,165	0,18
[alpha]$_2$	0,30	0,30	0,33	0,33	0,36

The following values of constant parameters are assumed: C_1 = 1,5MF, C_2 = 3 MF, R = 10 кohm, T = 0,1 sec. Therefore the values of the dimensionless parameters will be determined in the following form: [alhpa]$_1$ = 0,15: [alhpa]$_2$ = 0,30.

These values of dimensionless parameters [alhpa]$_1$ = 0,15 and [alhpa]$_{21}$ = 0,30 are accepted as main and the values of voltages and currents for them are determined. Then the values of the voltages and currents for the other values of these parameters are calculated in order to determine the responsiveness of the scheme when the parameters of the circuit elements are changing. In this case, we consider change in the capacitor capacitance in the circuit. For the numerical implementation of these calculations the accepted values of these parameters are listed in Table 1.

The solution to this linear problem for the values of the parameters [alhpa]$_1$ and [alhpa]$_2$ listed in Table 1 and also comparison of the obtained values with the voltages and currents in the circuit for their different values gave the following results:

- Change in capacitance of the first capacitor of 10% and at constant values of second capacitor capacitance led to reduction over time (with t = 0.03) of the voltage x_1 by 8,2% x_2 by 5,5% and the currents y_1 and y_1 no change.
- With the change of the parameter [alhpa]$_2$ of 10% and at a constant value of [alhpa]$_1$ voltage and current change is insignificant.
- The change of both parameters [alhpa]$_1$ and [alhpa]$_2$ by 10% led to reduction of voltages x_1 by 0% x_2 by 5,5% currents vary slightly by 8,1% and 8,1% respectively.
- The change of both parameters [alhpa]$_1$ and [alhpa]$_2$ by 20% led to reduction of voltages x_1 by 15,5% x_2 by 27,7% currents vary slightly by 14,9% and 14,9% respectively.

Problem Statement for Non-linear Circuit: Let's now consider the electric circuit with a nonlinear element (Figure 2). As an example, consider the scheme discussed above, but here a linear element is replaced by a nonlinear element (NE). The solution to the problem of transient process in a nonlinear circuit should be used to analyze the responsiveness of the given scheme and for

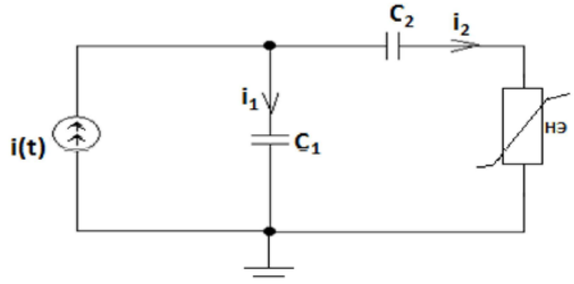


Fig. 2: Electric circuit with a nonlinear element

comparison with the results obtained from the solution of the linear problem. This allows us to determine the effect of the nonlinear element on the responsiveness of the circuit.

Here the development of a mathematical model for the transient process in the given circuit and formulation of a mathematical statement of the problem to determine the responsiveness due to changes in the parameters of its elements are required. In this case, the effects of the changes in the capacitances of the capacitors C_1 and C_2 will be considered.

Mathematical model of the electric circuit with a nonlinear element. Generation Method for circuit equations of state based on Kirchhoff's laws is the same as in the case of linear resistive circuits [1]. However, the process of solving the resulting system, which contains a non-linear equation, can be significantly hampered. For most of the relatively complex circuits the analytical solution of the systems of equations may not exist. Then you have to resort to numerical methods.

To produce a mathematical model of the electrical circuit (Figure 5) the following notations are introduced: i_1,i_2- currents, u_1, u_2, u_{NE} - voltages, C_1,C_2 capacitor capacitances, [tau]-time. Here C_1 and C_2 are considered constant values.

According to Kirchhoff's law for this circuit the following formulas hold: $i_1 + i_2 = i([tau])$, u_1, u_2, u_{NE} In series connection of capacitor C_2 and the NE current remains the same, i.e. $i_2 = i_{NE}$.

The equations determining the dependence of the current and voltage for the capacitors are written as the following formulas: a) for the first capacitor $i_1 = C_1 \cdot \frac{du_1}{d[tau]}$;

b) for the second capacitor $i_2 = C_2 \cdot \frac{du_2}{d[tau]}$.

Let the following expression be used to approximate CVC (current voltage characteristics) of the non-linear element (NE) $i_{NE} = \frac{U_0}{R} \cdot f(x)$, , where $x = \frac{u_{NE}}{U_0}$ - dimensionless voltage, $f(x)$ - approximating function for the relationship between current and voltage in a nonlinear element. In contrast to the problem discussed in [9], instead of a linear element with constant resistance R, in this problem a non-linear element is used. Moreover, the voltage in the non-linear element is determined by the formula $u_{NE} = x \cdot U_0$.

If $i_{NE} = i_2$, then for this circuit the following equations can be written:

$$\begin{cases} i_2 = C_2 \cdot \dfrac{du_2}{dt}; \quad i_1 = C_1 \cdot \dfrac{du_1}{dt}; \\ i_1 + i_2 = i(t); \quad u_{NE} = u_1 - u_2; \\ i_2 = \dfrac{U_0}{R} \cdot f(x) \end{cases}$$

In this system of five equations, the unknowns are the five variables $i_1, i_2, u_1, u_2, u_{NE}$. These five formulas are equations to define the five unknown parameters of the given electric circuit.

For convenience in the calculations dimensionless parameters should be used. For this purpose, specific quantities introduced in formulas (1) are used: U_o - voltage $\frac{U_0}{R}$ - current. The following replacement of variables is performed:

$$i_2 = y_2 \cdot \frac{U_0}{R}; \quad i = z \cdot \frac{U_0}{R}; \quad i_1 = y_1 \cdot \frac{U_0}{R};$$
$$x_1 = \frac{u_1}{U_0}; \quad x_2 = \frac{u_2}{U_0}; \quad x = \frac{u_{NE}}{U_0}; \quad t = \frac{[tau]}{T}.$$

Here $x, x_1, x_2, y_1, y_2, t -$ dimensionless values.
If u_1 and u_2 are x_1, x_2, y_1, y_2: found, it is

$$y_1 = [alpha]_1 \cdot \frac{dx_1}{dt}; y_2 = [alpha]_2 \cdot \frac{dx_2}{dt}, \qquad (14)$$
$$y_1 + y_2 = z(t); \quad y_2 = f(x).$$

Here the dimensionless voltage in non-linear element is determined by the formula $x = x_1 - x_2$; constants $[alpha]_1 = \frac{RC_1}{T}$ and $[alpha]_2 = \frac{RC_2}{T}$ are dimensionless quantities, RC_1 and RC_2 - time constants.

So, we obtain the following system of differential equations with respect to the unknown functions $x(t), x_1(t), x_2(t)$:

$$\begin{cases} \dfrac{dx}{dt} + \dfrac{[alpha]_1 + [alpha]_2}{[alpha]_1 \cdot [alpha]_2} \cdot f(x) = \dfrac{1}{[alpha]_1} \cdot z(t); \\ \dfrac{dx_1}{dt} = \dfrac{1}{[alpha]_1} \cdot \left[z(t) - f(x) \right]; \\ \dfrac{dx_2}{dt} = \dfrac{1}{[alpha]_2} \cdot f(x) \end{cases} \qquad (15)$$

Differential equations included in this system contain the function $f(x)$ that is non-linear with respect to $x(t)$ That is why the system of equations (15) is treated as nonlinear.

For the electronic circuit considered here it is assumed that at the initial moment of time there was no current (voltage), so for the solution of the given system of differential equations (15), the following initial conditions hold:

$$x_1(0) = 0; \quad x_2(0) = 0; \quad x(0) = 0; \qquad (16)$$

Now we can formulate the following statement of the mathematical problem: find such values of the unknown functions that satisfy the system of differential equations (15) and initial conditions (16). The solution of this system is searched for in the interva $x = x_1 - x_2$. Due to the fact that there is a formula $t \in [0,1]$ that relates these three functions, the solution of two differential equations, of the second and third equations of system (15) suffices.

If the values of the dimensionless functions $x_1(t), x_2(t), x(t),$ which determine the voltages are found, then the dimensionless variables that determine the currents $y_1(t)$ and $y_2(t),$ are found from the formulas (14):

$$y_2 = f(x), \quad y_1 = z - y_2. \qquad (17)$$

Numerical method solution of the mathematical problem. Mathematical problem (15) - (16) is the Cauchy problem for a system of nonlinear differential equations of the first order, solved for the derivatives. To solve this problem we cannot use existing analytical methods because of the presence of a nonlinear function in the equations, therefore a numerical method is used for solving the problem. Euler method can be chosen as a numerical method.

According to this method, initially a step is chosen for the independent variable t: [$sigma$] =0.0001 and then the substitution of derivatives by finite-difference equations is performed:

$$\frac{dx_1}{dt} \approx \frac{x_{1i+1} - x_{1i}}{[sigma]}; \quad \frac{dx_2}{dt} \approx \frac{x_{2l+1} - x_{2i}}{[sigma]}. \qquad (18)$$

Here $x_{1i} = x_1(t_i), \quad x_{2i} = x_2(t_i), \ t_i = [sigma] \cdot i, \quad i = 0,1,2,...,n$, $n = \frac{1}{[sigma]}$ – number of steps through the independent variable t.

Using the substitution (18), from the second and third equations (15), the following formulas for determining discrete values of the unknown functions $x_1(t)$ and $x_2(t)$: can be obtained:

$$x_{1i+1} = \frac{[sigma]}{\alpha_1} \cdot [f(x_i) - z(t_i)], x_{2i+1} = \frac{[sigma]}{\alpha_2} \cdot f(x_i), \qquad (19)$$

where $x_i = x(t_i) -$ values of the function $x(t)$ at $t= t_i$ These formulas hold for the values of parameter $i = 0, 1, 2, \ldots, n-1.$. From the initial conditions (16) it follows that

$$t_0 = 0, \quad x_{10} = 0, \quad x_{20} = 0. \qquad (20)$$

Problem Solution Algorithm: The solution of this problem consists of the following components:

- First the problem of approximation of nonlinear relationships between current and voltage is considered, solution of which results in the necessity to select approximating functions;
- Then use the selected functions to describe these relationships during solution of mathematical problems that arise in the modelling of a process in the circuit.

To develop an algorithm for solving a mathematical problem the following notations are introduced: $x_{1i} = p1, \quad x_{1i+1} = p, \quad x_{2i} = q1, \quad x_{2i+1} = q.$ Then formulas (19) will be written as follows:

$$p = p_1 + [sigma] \cdot (f(x) - z(x)) / [alpha]_1; \\ q = q_1 + [sigma] \cdot f(x) / [alpha]_2; \qquad (21)$$

The design scheme for the solution of a mathematical problem (15) - (16) will consist of the following stages:

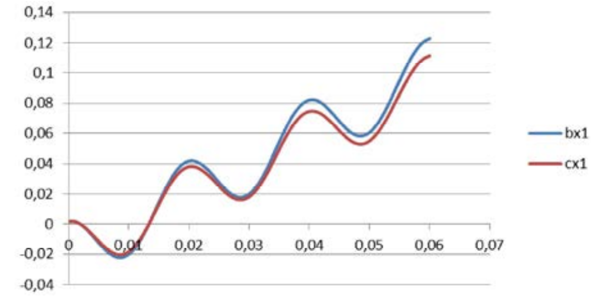
1^0 = Initial conditions: $t = 0$, $p = 0$, $q = 0$,
2^0 = Start of the loop $i = 1$
3^0 = Determination of the previous values of the functions $p_1 = p$, $q_1 = q$,
4^0 = Calculation of the next values of the functions from formulas (21).
5^0 = Calculation of the function values $x(t), y_1(t), y_2(t).$
6^0 = Output the results of problem solution.
7^0 = Increment i
8^0 = If $i \leq n$ move to step 3^0.

This solution algorithm is designed for all types of functions $f(x)$ and $z(t)$ Special cases, when more specific types of these functions are given, will be considered below. From the analysis of different types of functions we can claim that for the approximation of the current-voltage characteristics of the electronic circuit elements, the following can be used: a quadratic function $y = a \cdot x^2 + b \cdot x + c$, exponential function $y = a \cdot (1 - \exp(-x/a))$ and others. Every time a non-linear element is used, it is necessary to conduct experiments and determine the approximated function according to experimental data. Here a special case in which an approximating function $y = a \cdot x^2 + b \cdot x + c.$ is used for the analysis of the electronic circuit.

Special Case, When the Function $y = a \cdot x^2 + b \cdot x + c.$ is Assumed as an Approximating Function: Analysis of various types of approximating functions showed [4] that for any kind of current-voltage characteristics a quadratic function $y = a \cdot x^2 + b \cdot x + c.$ can be used. Therefore for the special case considered here this function is used to describe the dependence of current from voltage in a nonlinear element. For specific calculations parameters of an example considered for a bipolar transistor, where the coefficients of the approximating function are as follows: a = -0,0098, b = 0,1627, c = 0,3007 are adopted.

Here, the current source is also considered a variable and change in the current is set in the form of a sine wave: $z(t) = \sin(2[pi] f t),$ where the frequency f = 50 Hz. The same values of the constant parameters are assumed: C_1 = 1,5 MF, C_1 = 3 MF, R = 10 kOhms, T = 0,1 sec. The values: $[alpha]_1$ = 0,15, $[alpha]_2$ = 0,3, are assumed as main values of the dimensionless parameters.

To determine the responsiveness of the given scheme to the change in the values of capacitors, this problem is solved for their different values. At constant R and T the change in capacitor capacities is determined by changing the values of parameters $[alpha]_1$, $[alpha]_2$ Here a computing experiment must be performed. For the computational experiment changes of dimensionless parameters $[alpha]_1$ and $[alpha]_2$ which determine the capacitor capacities shown in Table 1 are selected.



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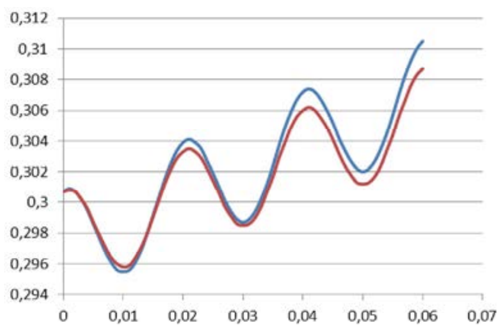

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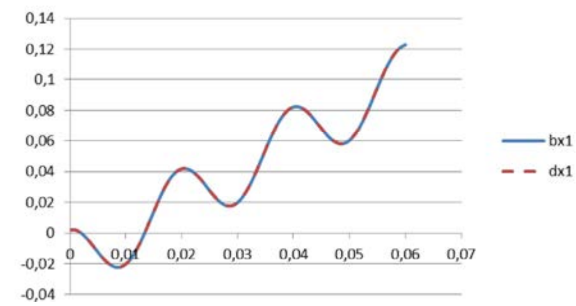
Fig. 3:



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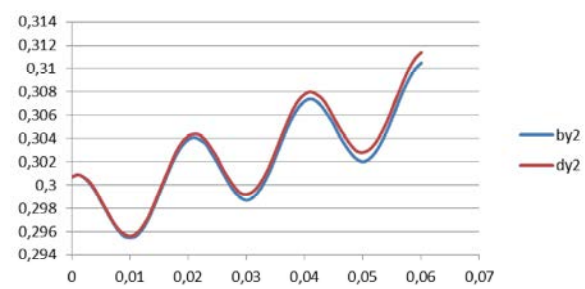

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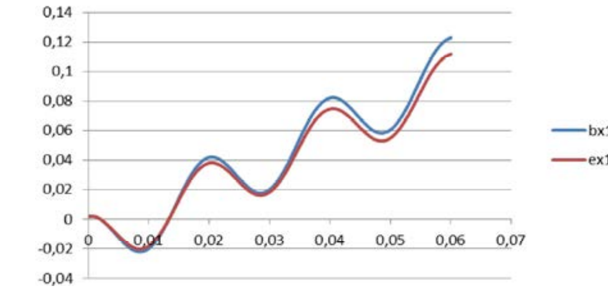
Fig. 4:



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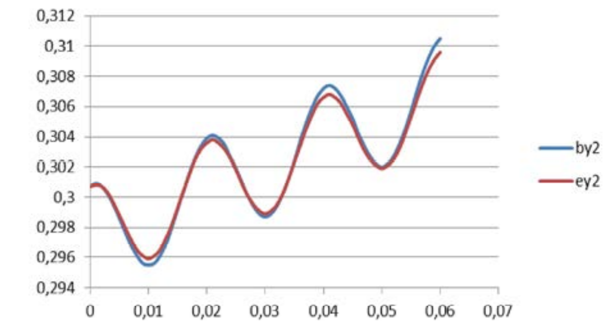

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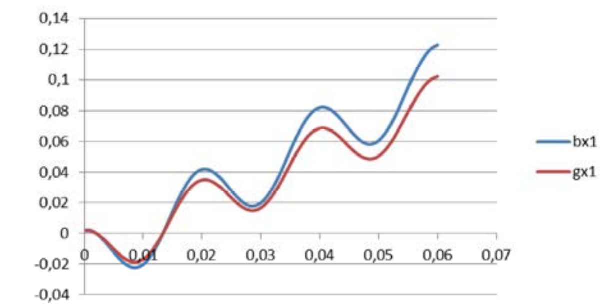
Fig. 5:



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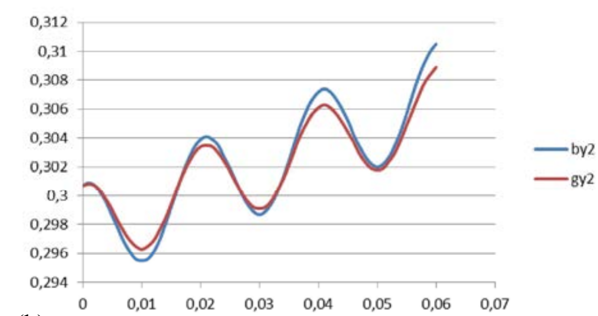

(b)

Fig: 6:

For a comparative analysis the first option (Table 1) is selected as the primary one and results of solving the problem for the other options are compared with the results of this option.

- The results of comparison for the first (primary) and second choices when the value of the parameter $[alpha]_1$ is increased by 10% and the value of the parameter $[alpha]_2$ remains constant, a change in voltage x_1 over time t occurs (Figure 3 a); for example, at time by 10%, at a time t= 0,04, by 9,2% at time t= 0,06 Change of the current is shown in Figure 3b, which shows the change in current; for example, at the following times t= 0,04 by 0,24%

- Effect of change in capacitance values of the second capacitor is greater than the change in the second capacitor capacity. For example, a comparison of the first and second options showed that when changing parameter [*alpha*]$_1$ by 10% difference of the voltage values x_1 (or u_1) and x_2 (or u_2) for these options was only 0% when the other options are from 9% to 17%.
- The same pattern is observed for the currents; as time flows, the difference of the current values increases when the parameter values of circuit elements change, in this case the values of the capacitors. Moreover, a greater change in the values of these parameters leads to a greater increase in the difference between the values of the voltages and currents (Figures 3-6).

CONCLUSION

This paper considered the problem of determining the responsiveness of the electronic circuit to change in its parameter values. Here we considered the transients in RC-circuit in two settings: with a linear and with a non-linear element. To solve the stated problems we initially set up their mathematical model, based on which mathematical problems have been formulated.

In the first case, the mathematical problem related to the Cauchy problem for a system of two linear differential equations was obtained, an analytic solution for which has been determined. The solution to the problem was used for responsiveness analysis of the considered scheme by way of comparing the solutions to this problem for different values of the circuit parameters, in this case the values of capacitor capacities.

In the second case, we obtained the Cauchy problem for a system of nonlinear differential equations of first order. This problem was solved numerically using Euler method. Here the various options for the change in the circuit elements (capacitors) were also discussed.

Findings: According to the results of the analysis of solutions to these problems we can conclude that:

- The approach to the determination of the responsiveness proposed in this paper can be extended to any kind of electrical circuits. Development of a mathematical model and the solution of mathematical problems in linear and nonlinear formulation can be solved and used to analyze the responsiveness of the circuit to the change in the parameter values of the circuit components.
- The responsiveness of the circuit during the transient process can be time-dependent and may increase over time (Figures 3,4,5,6). Moreover, the greater deviation of the values of the circuit parameters leads to a larger deviation of the current and voltage values over time.

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